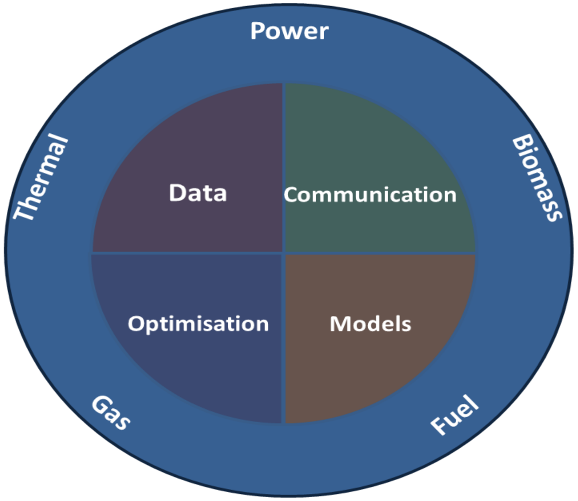
Methodologies for Operating Future Intelligent Wastewater Systems



Henrik Madsen, DTU Compute

http://www.henrikmadsen.org

http://www.smart-cities-centre.org

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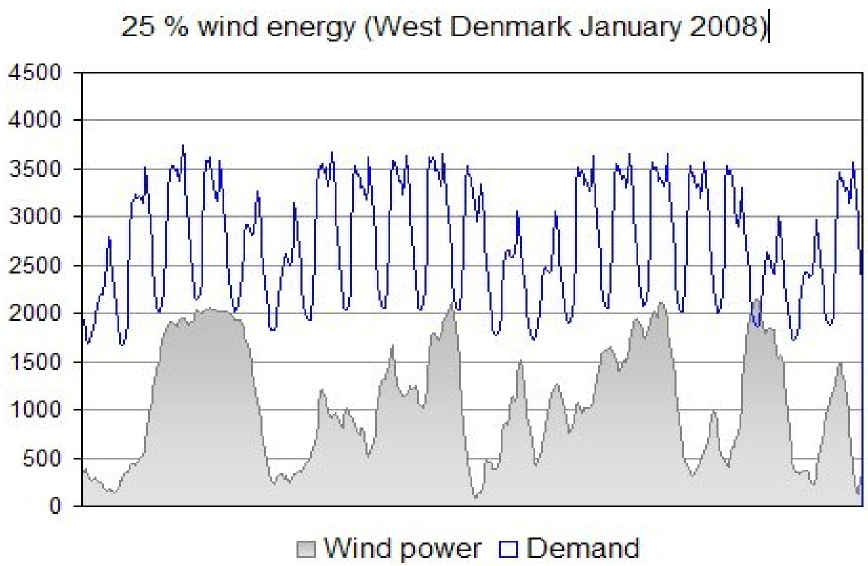
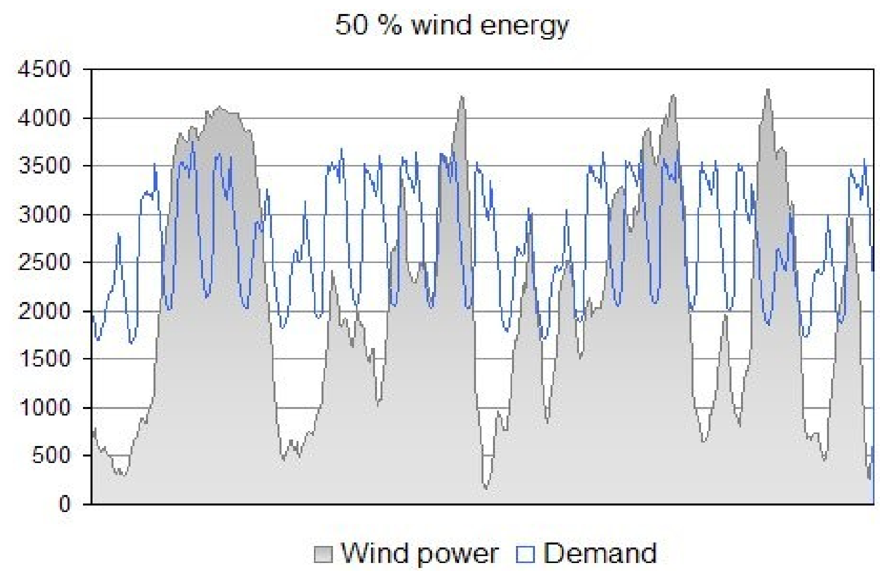
The Danish Wind Power Case

…. balancing of the power system



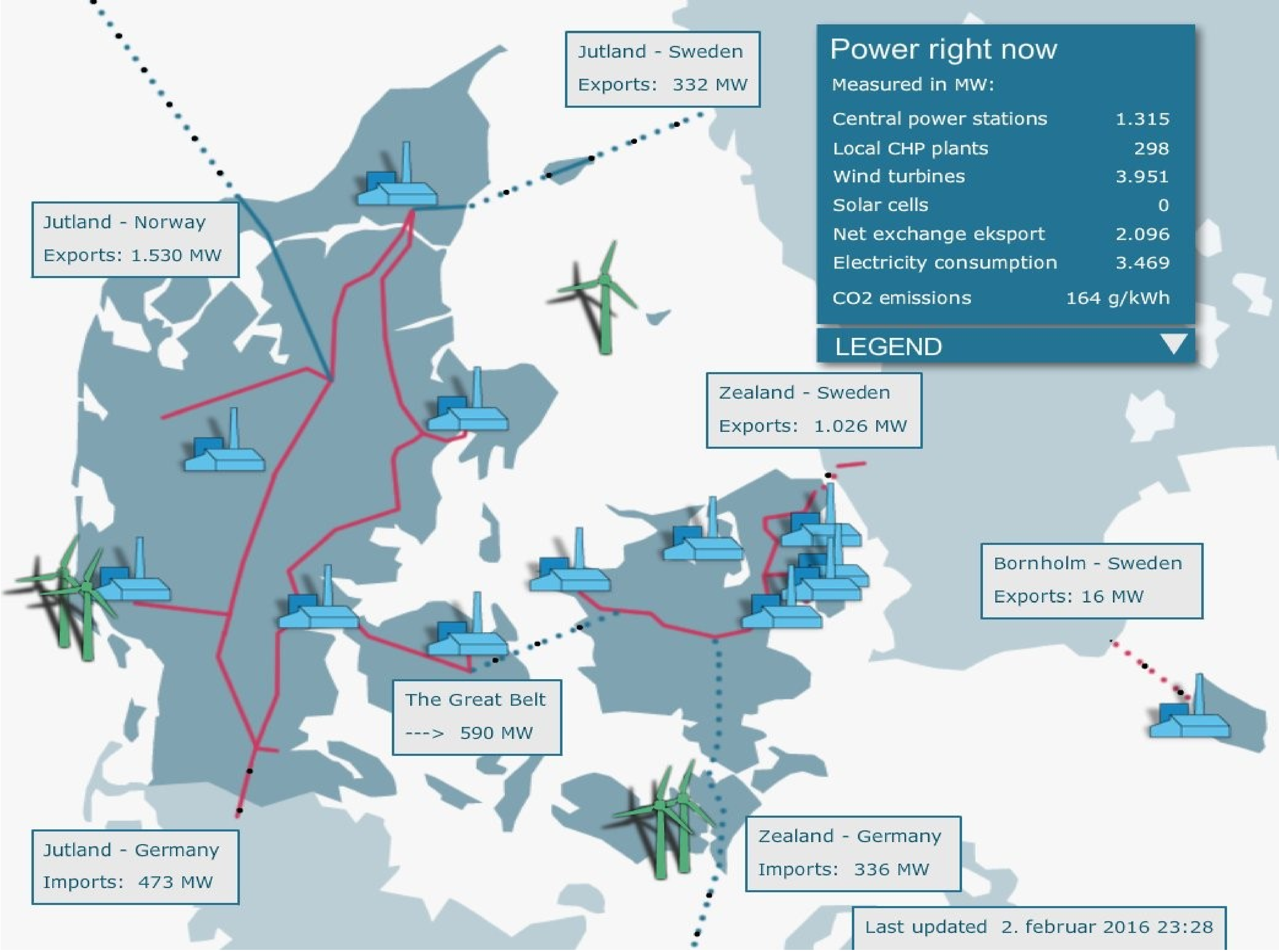
In 2008 wind power did cover the entire demand of electricity in 200 hours (West DK)



In 2015 more than 42 pct of electricity load was covered by wind power.

For several days the wind power production was more than 100 pct of the power load.

July 10th, 2015 more than 140 pct of the power load was covered by wind power



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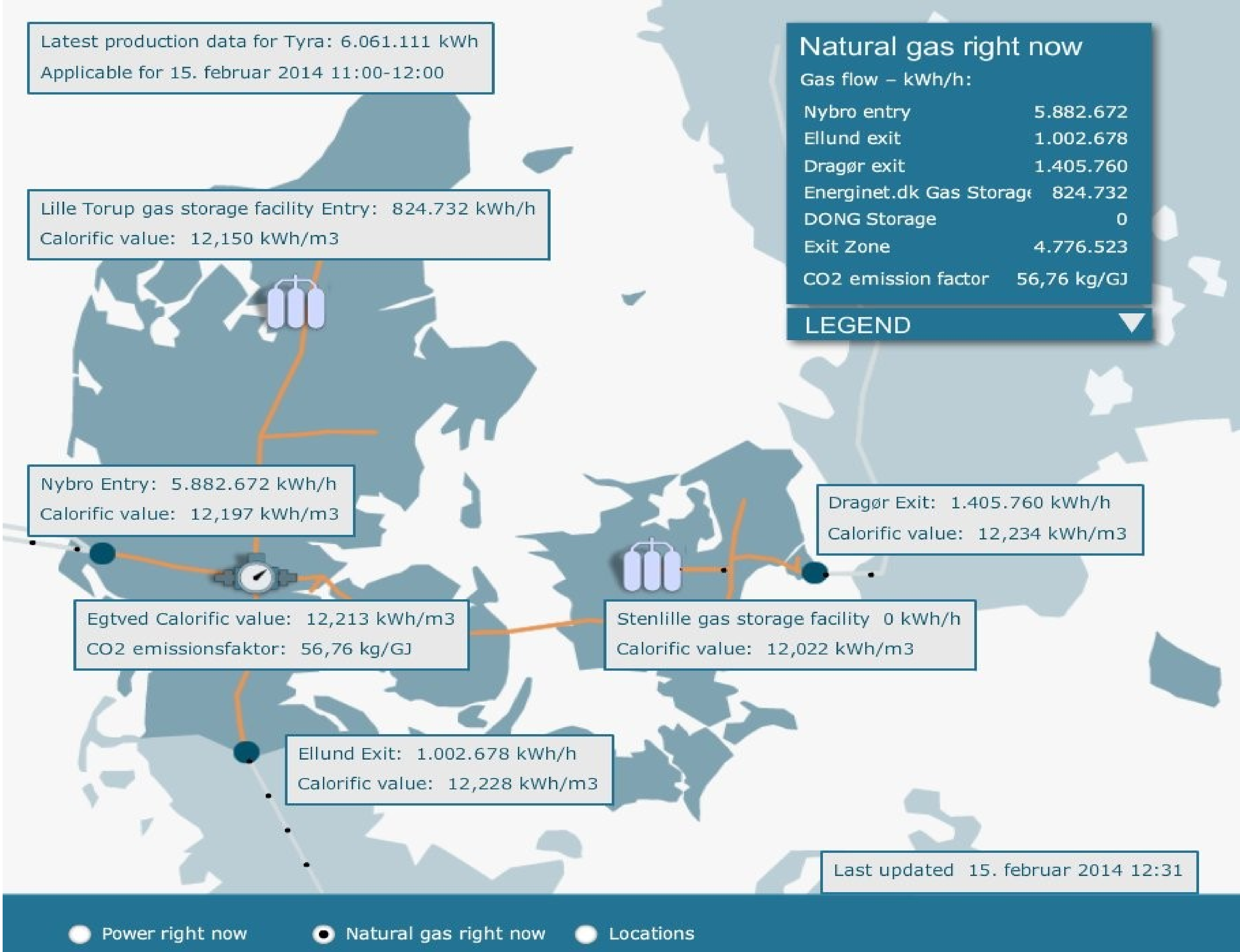
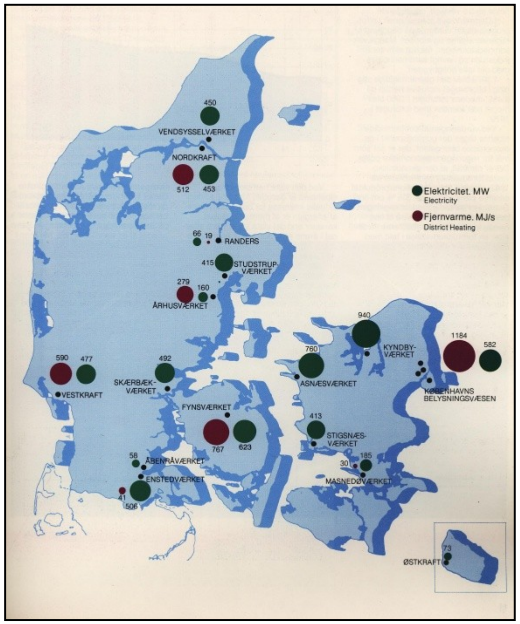

Latest production data for Tyra: 6.061.111 kWh
Applicable for 15. februar 2014 11:00-12:00
Natural gas right now
Gas flow – kWh/h:
Nybro entry 5.882.672
Ellund exit 1.002.678
Dragør exit 1.405.760
Energinet.dk Gas Storag 824.732
DONG Storage 0
Exit Zone 4.776.523
CO2 emission factor 56,76 kg/GJ
LEGEND
Lille Torup gas storage facility Entry: 824.732 kWh/h
Calorific value: 12,150 kWh/m3
Nybro Entry: 5.882.672 kWh/h
Calorific value: 12,197 kWh/m3
Dragør Exit: 1.405.760 kWh/h
Calorific value: 12,234 kWh/m3
Egtved Calorific value: 12,213 kWh/m3
CO2 emissionsfaktor: 56,76 kg/GJ
Stenlille gas storage facility 0 kWh/h
Calorific value: 12,022 kWh/m3
Ellund Exit: 1.002.678 kWh/h
Calorific value: 12,228 kWh/m3
Last updated 15. februar 2014 12:31
Power right now
Natural gas right now
Locations

From large central plants to Combined Heat and Power (CHP) production

1980



Today

*From a few big power plants to many small **combined heat and power** plants – however most of them based on coal*

DK has enough excess heat to cover the entire need for heating .... but ...

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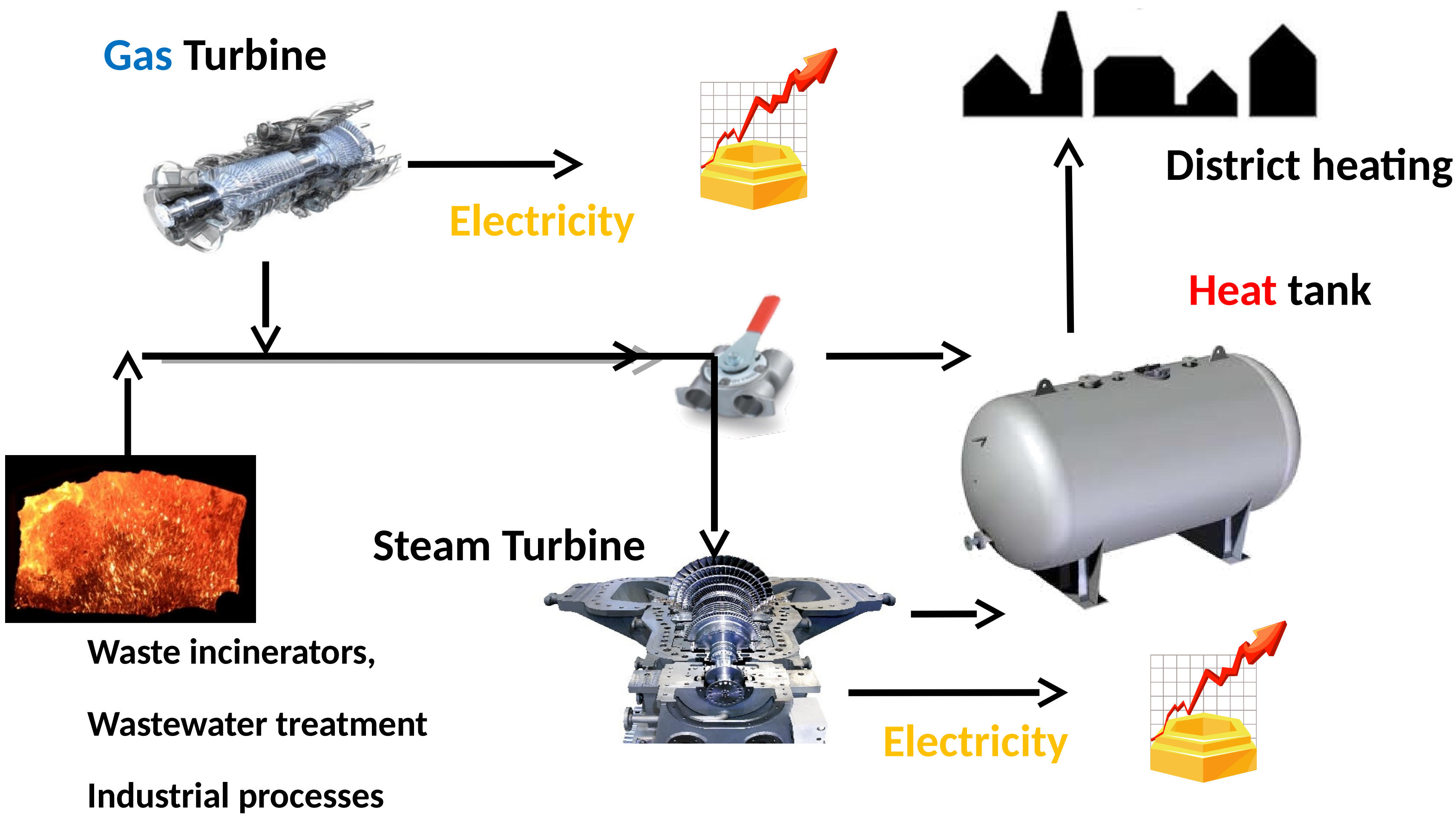
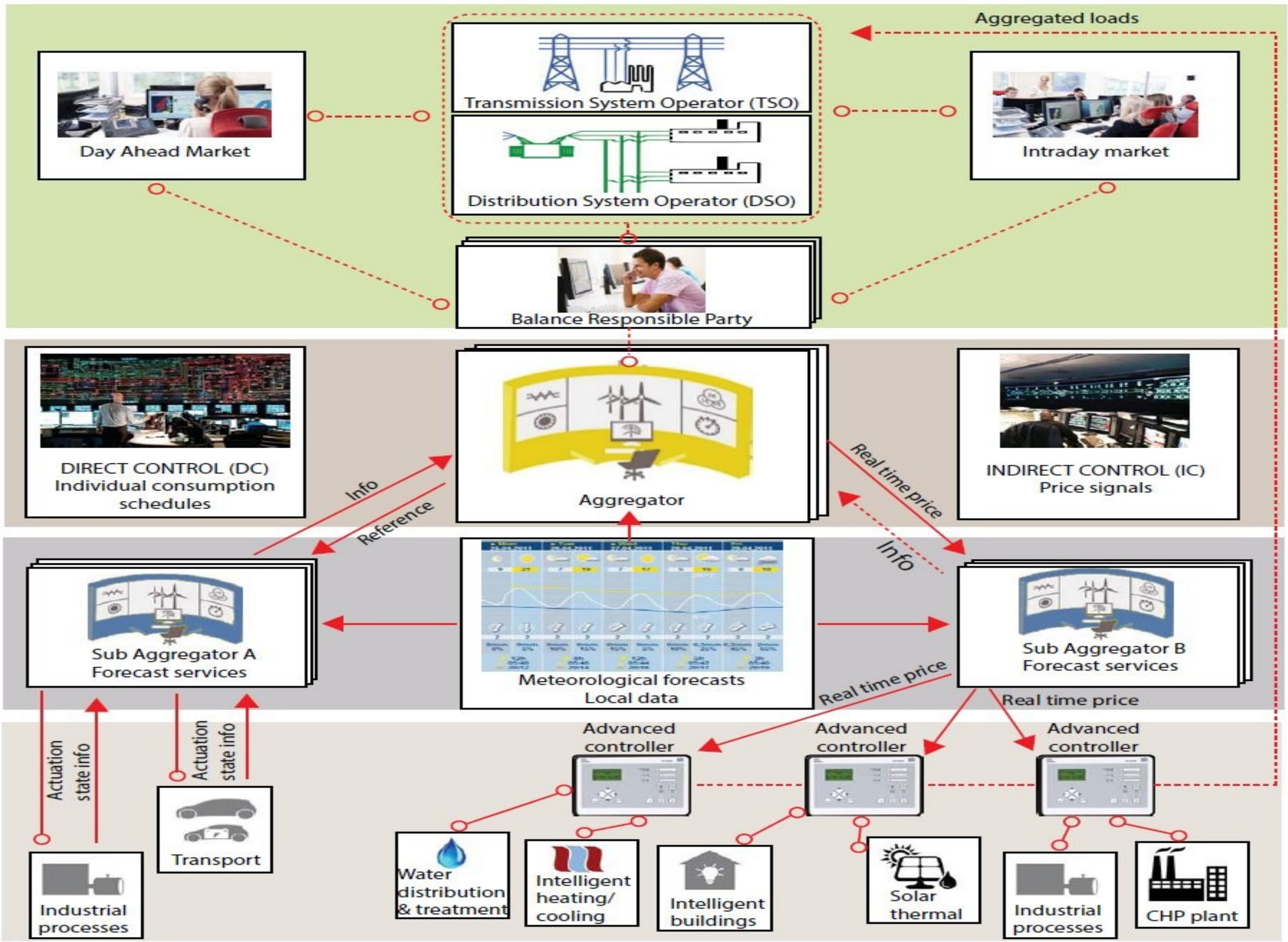
CHP and Integrated Energy Systems

(Paradigmatic example - Denmark)

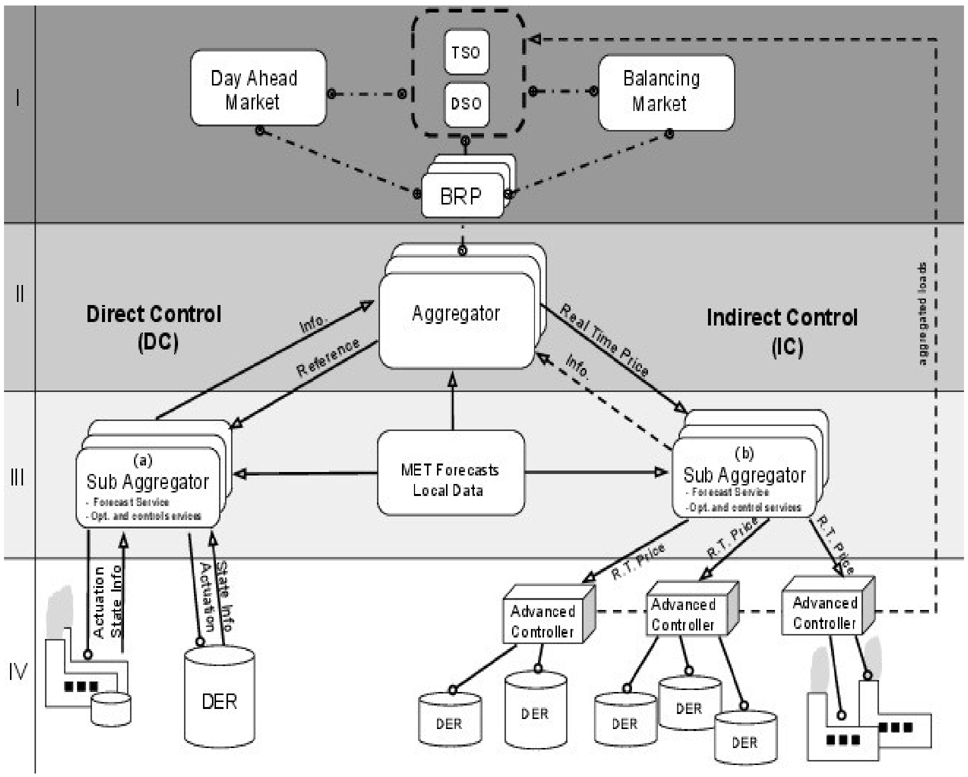


Smart-Energy OS



DTU

Control and Optimization



In New Wiley Book: Control of Electric Loads in Future Electric Energy Systems, 2015

Day Ahead:

Stoch. Programming based on eg. Scenarios

Cost: Related to the market (one or two levels)

Direct Control:

Actuator: **Power**

Two-way communication

Models for DERs are needed

Constraints for the DERs (calls for state est.)

Contracts are complicated

Indirect Control:

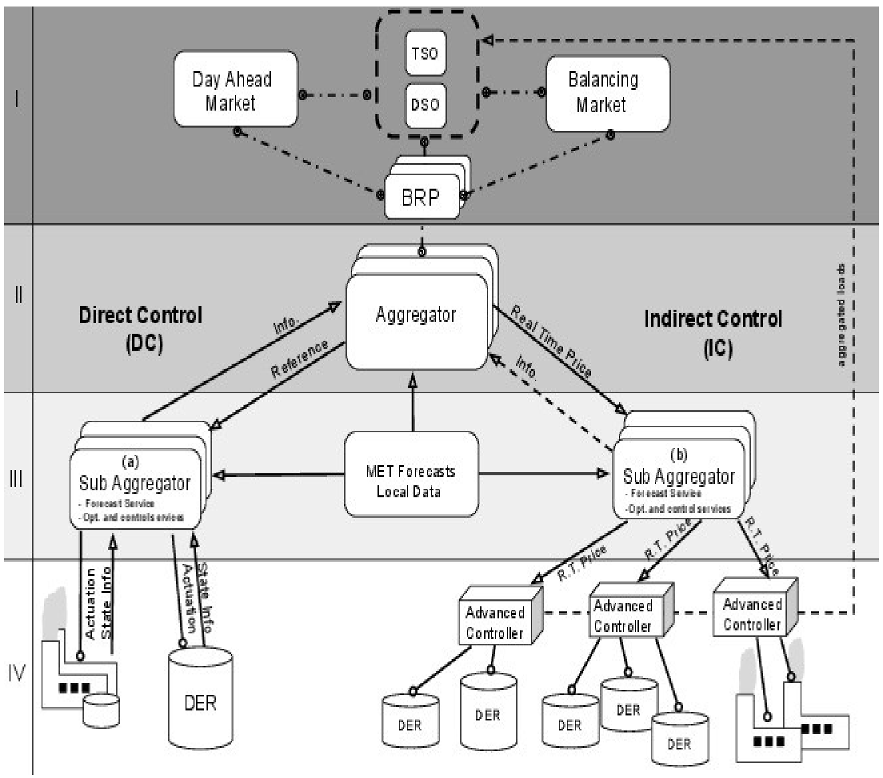
Actuator: **Price**

Cost: E-MPC at **low (DER) level**, One-way communication

Models for DERs are not needed

Simple 'contracts'

Forecast requirements



Day Ahead:

- Forecasts of loads
- Forecast of Grid Capacity (using eg. DLR)
- Forecasts of production (eg. Wind and Solar)

Direct Control: .

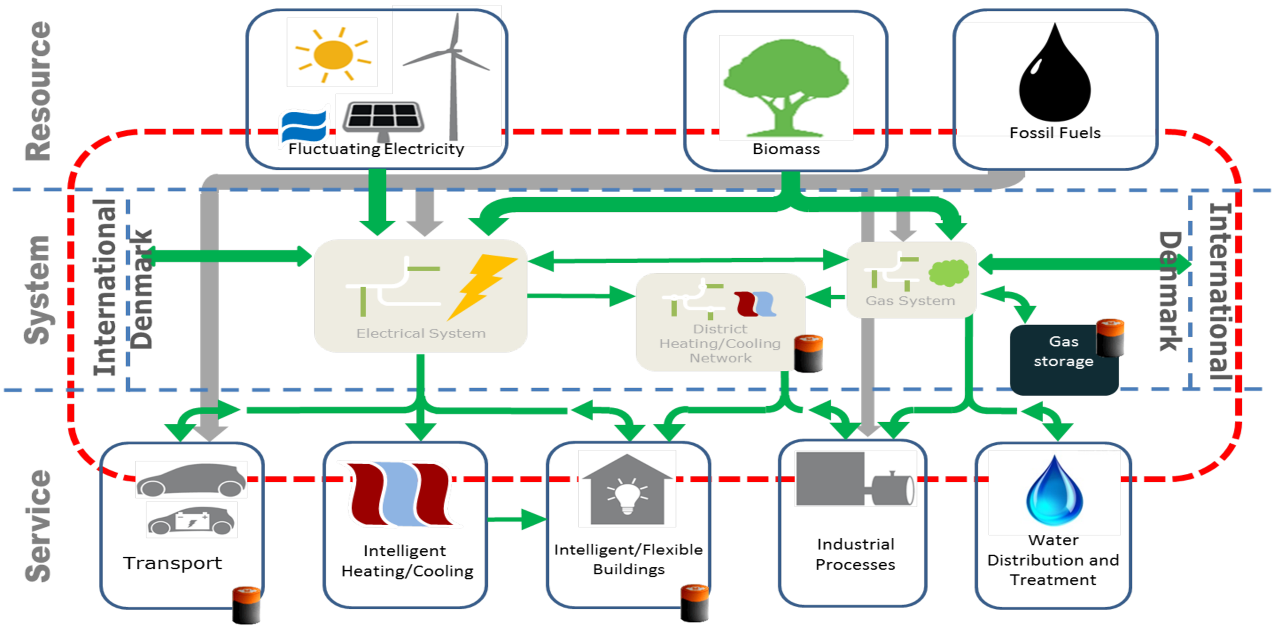
- Forecasts of states of DERs
- Forecasts of load

Indirect Control:

- Forecasts of prices
- Forecasts of load

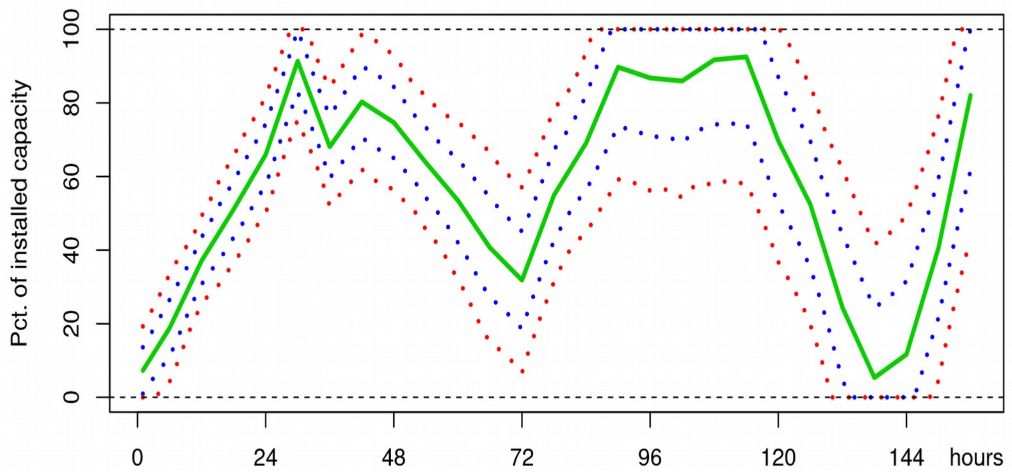
Cyber Physical Models

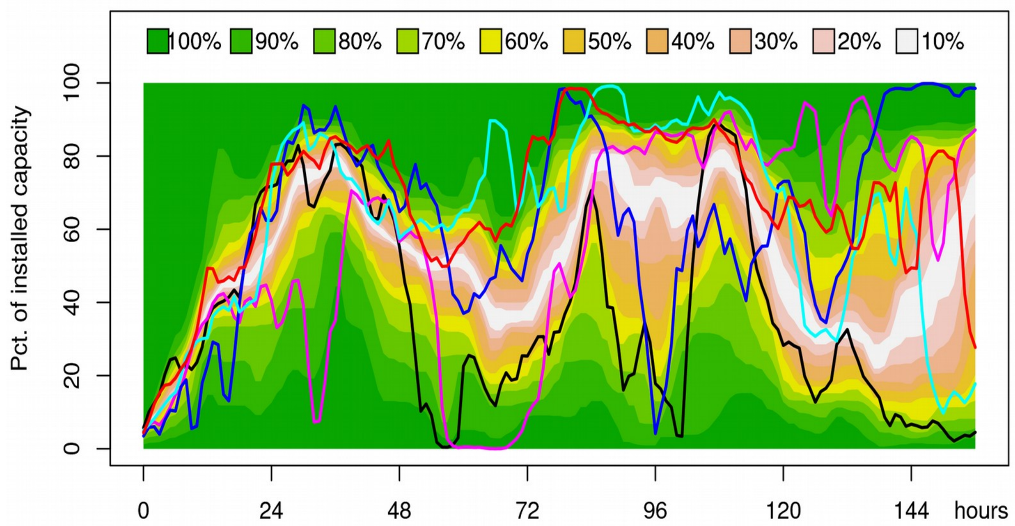
Grey-box modelling are used to establish **models and methods** **for real-time operation of future electric energy systems**



Which type of forecast?

- Point forecasts
- Conditional mean and covariances
- Conditional quantiles (Prob. forecasts)
- Conditional scenarios
- Conditional densities
- Stochastic differential equations





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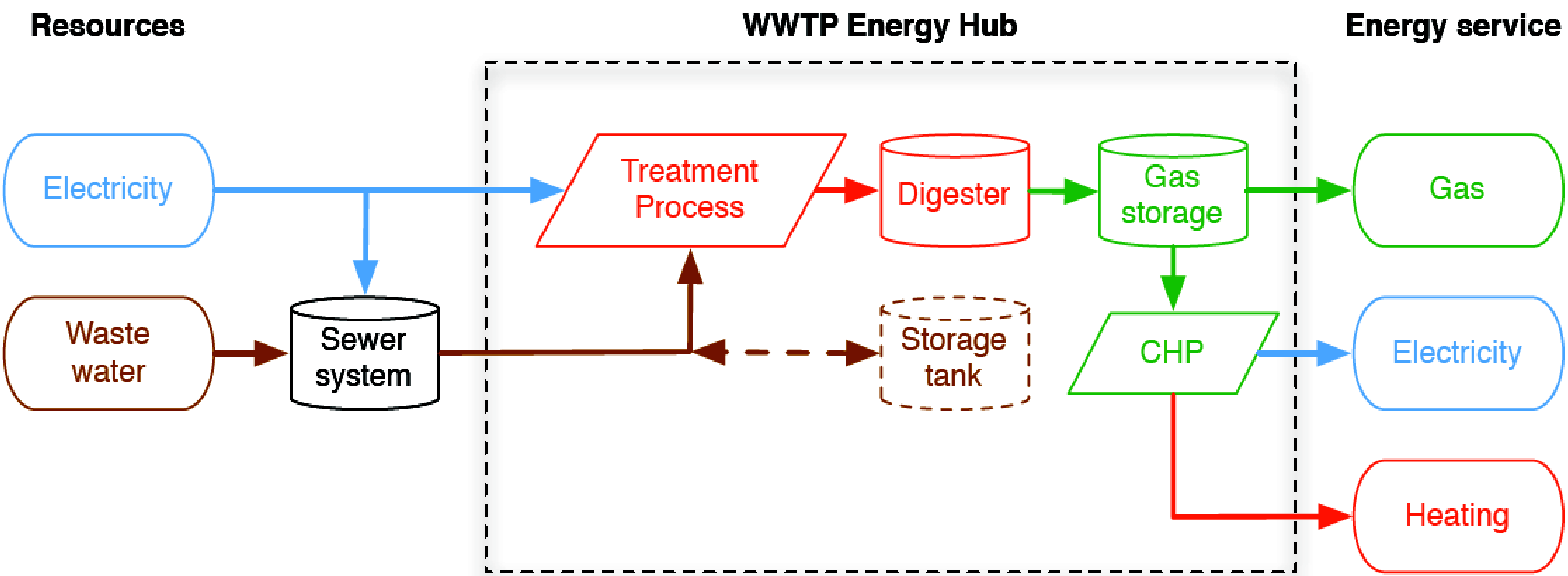
Case study

Control of Wastewater Treatment Plants

Waste-2-Energy



Kolding WWTP

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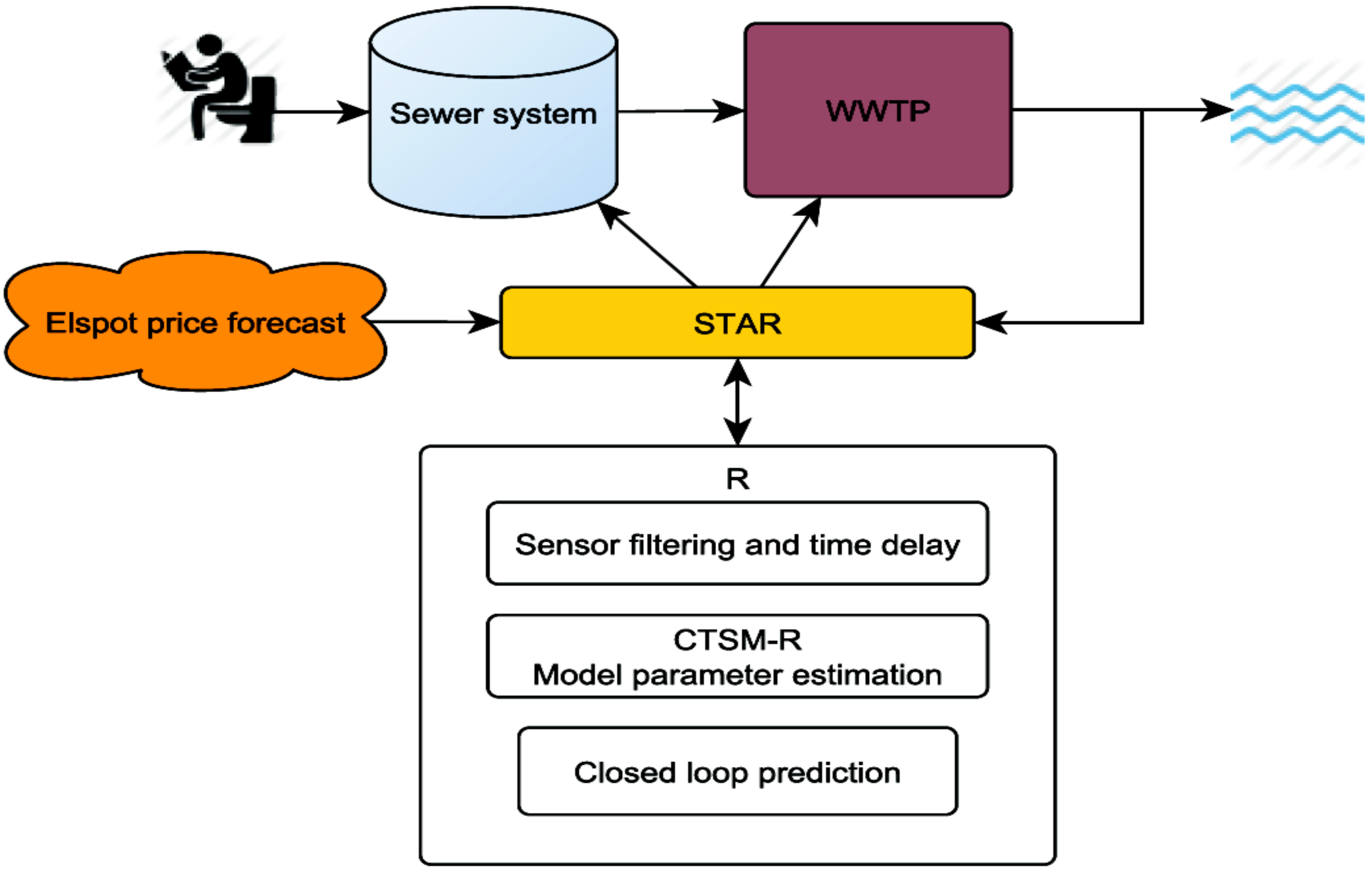
Energy Flexibility in Wastewater Treatment

- Sludge -> Biogas -> Gas turbine ->Electricity
- Power management of the aeration process
- Pumps and storage in sewer system

Overall goals:

- Cost reduction
- Minimize effluent concentration
- Minimize overflow risk

Energy Flexibility in Wastewater Treatment



WWTP Control goal

$$\text{minimize } p_{fee} Q^T S_N + p_{elspot}^T u$$

Activated Sludge Model (ASM) No. 1

$$\dot{S}_{NH} = -i_{XB}(\rho_1 + \rho_2) - \left(i_{XB} + \frac{1}{Y_A}\right)\rho_3 + k_a S_{ND} X_{B,H}$$

$$\dot{S}_{NO} = -\frac{1 - Y_H}{2.68 Y_H}\rho_2 + \frac{1}{Y_A}\rho_3$$

$$\dot{S}_O = -\frac{1 - Y_H}{Y_H}\rho_1 - \frac{4.57 - Y_A}{Y_A}\rho_3$$

$$\dot{S}_S = \rho_7 - \frac{1}{Y_H}(\rho_1 + \rho_2)$$

$$\dot{X}_S = (1 - f_p)(b_H X_{B,H} + b_A X_{B,A}) - \rho_7$$

$$\dot{X}_{B,H} = \rho_1 + \rho_2 - b_H X_{B,H}$$

$$\dot{X}_{B,A} = \rho_3 - b_A X_{B,A}$$

$$\dot{S}_{ND} = \rho_8 - k_a S_{ND} X_{B,H}$$

$$\dot{X}_{ND} = (i_{XB} - f_p i_{XP})(b_H X_{B,H} + b_A X_{B,A}) - \rho_8$$

$(S_I,\ X_I,\ X_P,\ \text{and}\ S_{ALK})$

Reaction Rates in ASM No. 1

$$\rho_1 = \hat{\mu}_H \frac{S_S}{K_S + S_S} \frac{S_O}{K_{O,H} + S_O} X_{B,H}$$

$$\rho_2 = \hat{\mu}_H \frac{S_S}{K_S + S_S} \frac{K_{O,H}}{K_{O,H} + S_O} \frac{S_{NO}}{K_{NO} + S_{NO}} \eta_g X_{B,H}$$

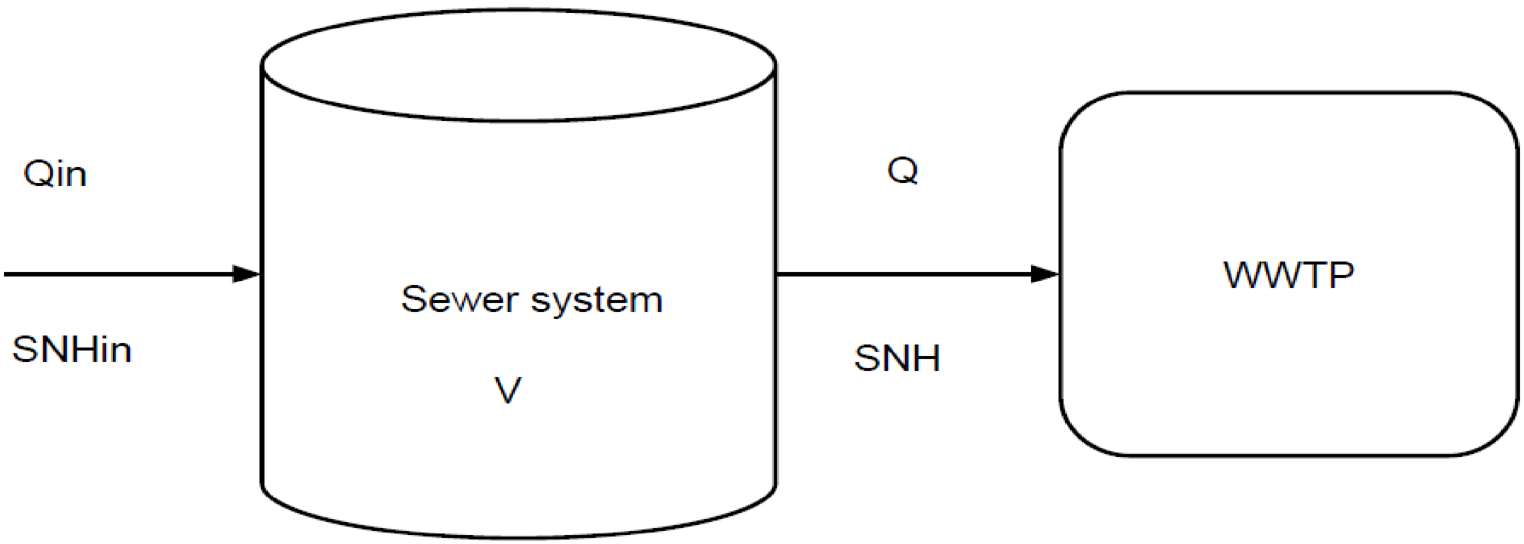
$$\rho_3 = \hat{\mu}_A \frac{S_{NH}}{K_{NH} + S_{NH}} \frac{S_O}{K_{O,A} + S_O} X_{B,A}$$

$$\rho_7 = k_h \frac{X_S/X_{B,H}}{K_X + X_S/X_{B,H}} \left(\frac{S_O}{K_{O,H} + S_O} + \eta_h \frac{K_{O,H}}{K_{O,H} + S_O} \frac{S_{NO}}{K_{NO} + S_{NO}} \right) X_{B,H}$$

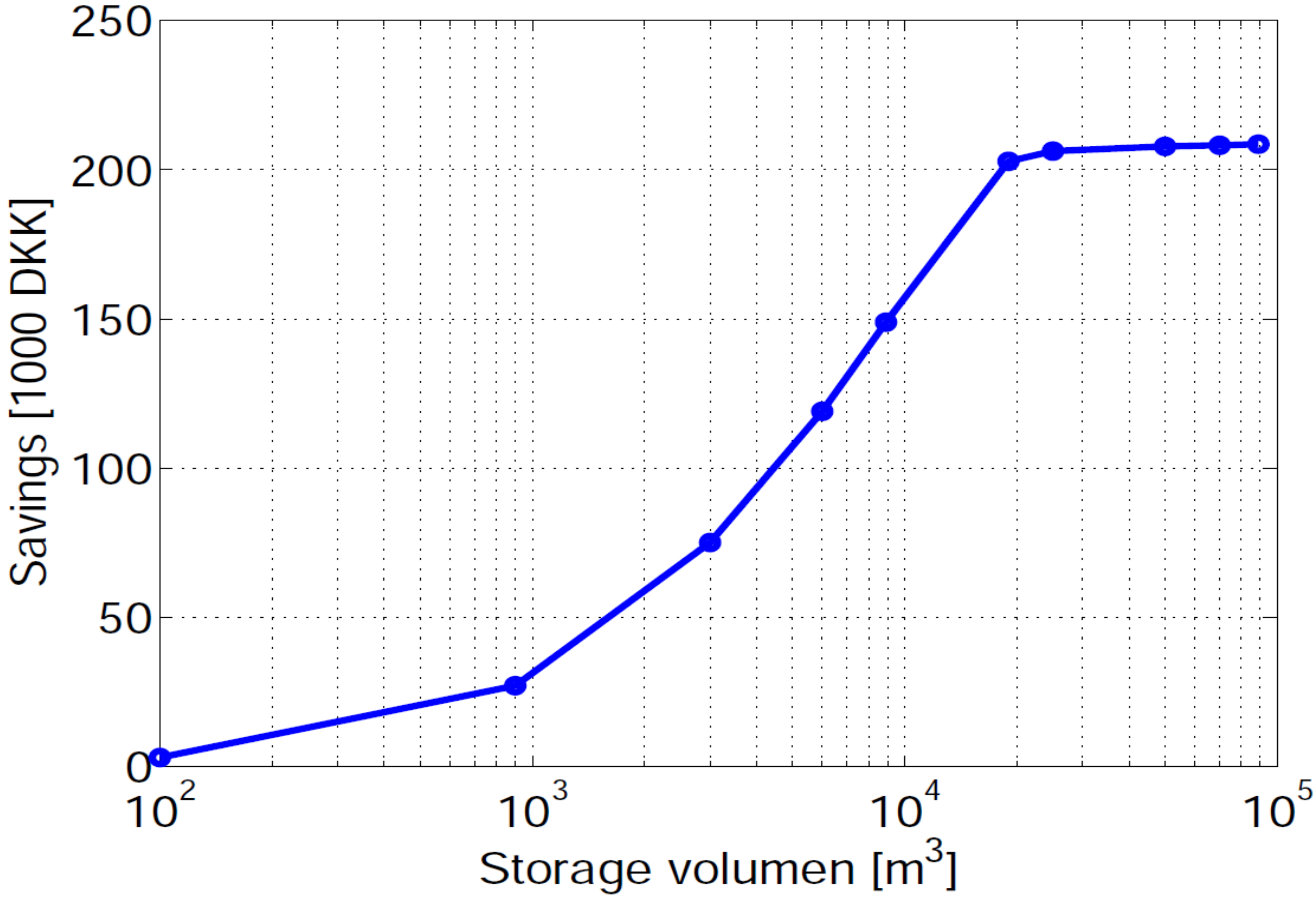
$$\rho_8 = \rho_7 \left(X_{ND}/X_S \right)$$

Sewer System Control Goal

$$\text{minimize overflow} + p_{elspot}^{T} f(Q)$$



Sewer System Annual Elspot Savings



Discussion

- IT-Intelligent Energy Systems Integration can provide virtual storage solutions (so maybe we should put less focus on electrical storage solutions)
- District heating (or cooling) systems can provide flexibility on the essential time scale (up to a few days)
- Gas systems can provide seasonal virtual storage solutions
- Smart Cities are just smart elements of a Smart Society
- We see a large potential in Demand Response. Automatic solutions, price based control, and end-user focus are important
- We see large problems with the tax and tariff structures in many countries (eg. Denmark).
- Markets and pricing principles need to be reconsidered; we see an advantage of having a physical link to the mechanism (eg. nodal pricing, capacity markets)

Summary

- **A framework for implementing flexible energy systems related to wasterwater handling in smart cities has been described**
- **Flexibility both in sewer systems and at the wasterwater treatment plant**
- Built on: Big Data Analytics, Cyber Physical systems, Stochastic opt./control, Forecasting, IoT, IoS, Cloud computing, ...
- **Modelling**: Toolbox – CTSM-R - for combined physical and statistical modelling (grey-box modelling)
- **Control:** Toolbox – MPC-R - for Model Predictive Control
- **Simulation:** Framework for simulating flexible power systems.